SIMULATION OF UNSIGNALIZED INTERSECTIONS FOR INDIAN ROAD CONDITIONS

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by

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CERTIFICATE

This is to certify that this M.Tech thesis work entitled **SIMULATION OF UNSIGNALIZED INTERSECTIONS FOR INDIAN ROAD CONDITIONS** *has been carried out by* **Kothapalli Srinivas** *under my supervision and it has not been submitted elsewhere for a degree.*

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K.Srinivas

Abstract

Intersections in highway and street networks are of importance to the traffic engineer who is responsible for design and operation of these facilities. They are generally a major bottleneck for smooth flow of traffic and major traffic delays as well as accidents take place on these locations. Thus there is a great need to properly study and subsequently design intersections on the road networks.

Unsignalized intersections are the most common type of intersections that we encounter on the Indian road network. Yet, they are least understood and the techniques to analyze their performance are not well developed. Unsignalized intersections in Indian road network are difficult to study as they are difficult to model. The complexity to model them arise due to the highly heterogeneous mix of vehicle types, indisciplined driver behaviour as well as the difficult problems of gap-acceptance and queuing which characterize any unsignalized intersection.

The main objective of this study is to develop a model of unsignalized intersections in the Indian road networks. An attempt is therefore made to develop a computer simulation based queuing model of such intersections. The model can handle various movements and vehicle types and can provide as output, the delays to each vehicle, queue lengths at every instant of time as well as a variety of other performance measures such as average delay, average queue length, etc.

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Chapter 1

INTRODUCTION

Transportation contributes to the economic, industrial, social and cultural development of any country. Traffic engineering is that branch of transportation engineering which deals with the study and design of traffic facilities. With the continuous increase in population and corresponding growth of vehicles, the traffic facilities have come under a heavy strain in most of major cities. Hence there is a need to improve the efficiency of the existing facilities.

One of the most important facilities on any road network are intersections. This is so, because they are bottlenecks on any road network and their improvement generally improves the performance of the entire network. Amongst, the intersections, many are unsignalized atleast for some part of the day. Hence, improvement of unsignalized intersections through signalization/ channelization is or should be of high priority.

One of the first steps in improving any facility is to be able to study it and model it reasonably realistically. Hence, in this thesis, an attempt is made to develop a model of unsignalized intersections under Indian conditions. It may be noted here, that most of the models of unsignalized intersections that exist are not applicable to Indian conditions. This is due to the particularly

unruly traffic flow that is observed in Indian unsignalized intersections.

Given the complexity of traffic flow in Indian unsignalized intersections no attempt was made to develop an analytical model. Rather, it was felt that the only option was to develop a simulation model of the traffic flow at such intersections. Hence in this thesis a simulation model of an unsignalized intersections is developed.

The thesis is divided into six chapters of which this is the first. The second chapter defines the problem studied here. Chapter three presents a review of existing literature on the topic of modeling of unsignalized intersections. Chapter four describes the proposed model in detail. The fifth presents the results obtained from the proposed model. Chapter six presents conclusions and directions for future work.

Chapter 2

PROBLEM STATEMENT AND MOTIVATION

In this chapter, the problem of modeling unsignalized intersection is briefly discussed.

Intersections in highway and street networks are of importance to the traffic engineer who is responsible for design and operation of these facilities. They are generally a major bottleneck for smooth flow of traffic and major traffic delays as well as accidents take place on these locations. Studies in India have shown that 30 to 35 percent of total accidents occur at intersections. So there is a great need to properly study and subsequently design these intersections. However, unsignalized intersections in Indian road network are difficult to study as they are difficult to model. The complexity to model them arise due to the highly heterogeneous mix of vehicle types and indisciplined driver behaviour (in the sense of traffic discipline). In majority of the unsignalized intersections, we observe that the drivers are impatient and try to dominate to get the right-of-way. For example every driver tries to occupy the top position in the queue which leads to indisciplined queuing; or drivers try to inch their way into the intersection in an attempt to get the right-of-way, this often leads

to the formation of queues at the middle of the intersection. These peculiarities of Indian unsignalized intersections add to the already difficult problem of gap-acceptance and queuing which characterize any unsignalized intersection. The result makes Indian unsignalized intersections almost impossible to be modeled using analytical techniques.

This fact motivated us to develop a simulation model for Indian unsignalized intersections. The simulation model is based on the following picturization of an Indian unsignalized intersection.

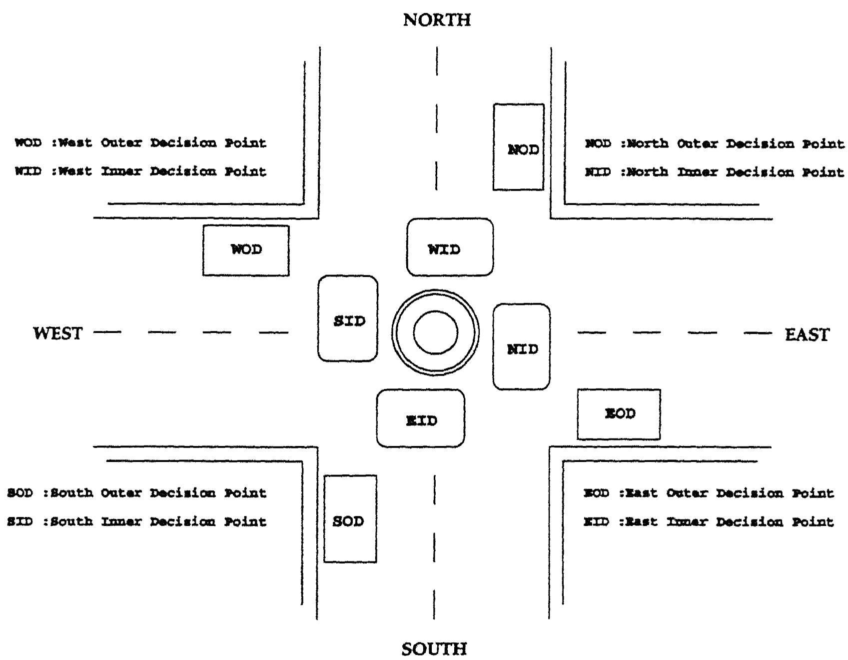


Figure 2.1: Typical view of the Unsignalized Intersection

It is assumed that the intersection consists of various decision points (as it has been shown in the figure 2.1.). Vehicles moving in the intersection go through one or more of these decision points. The process of vehicular movement assumed in this study is best explained through an example. Consider, the vehicles on the southern approach to the intersection; the left-turning vehicles approach the point SOD, look for a gap in the in the conflicting stream

and then turn left; the through vehicles, on the other hand, after accepting a gap on reaching the SOD join the queue at SID and then accepts a gap on reaching the top of this queue and subsequently leave the intersection; while the right-turning vehicles after having crossed the SOD and SID join the queue at WID which it then crosses to leave the intersection on finding a suitable gap. It should be noted here, that at each decision points the vehicle which is at the top of the queue looks at the gaps in its conflicting stream and accepts a gap based on a probabilistic gap acceptance rule.

Although certain simplifying assumptions are made here, like the queue formation is disciplined, it is felt that the present view of the unsignalized intersection is a step towards achieving realism in modeling Indian unsignalized intersections.

Chapter 3

LITERATURE REVIEW

3.1 General

Any traffic network consists of numerous signalized and unsignalized intersections. At these points conflicting streams of traffic compete for the right-of-way. Typically these points form the bottlenecks of traffic networks. One of the goals of traffic engineers therefore is to design and operate such intersections/facilities efficiently. One of the logical measures of efficiency is the delay faced by vehicles at these facilities and hence it has been the endeavour of traffic engineers to design intersections which offer the least delay possible. The first step in describing an efficient intersection is to understand the flow pattern at these intersections and the relationships between the different design elements of the intersections and delay to vehicles. In this chapter, a review of the previous work done in this regard for unsignalized intersection is presented. The chapter also highlights why these models cannot be applied to unsignalized intersections in Indian conditions.

3.2 Analytical Models

An analytical traffic flow model is specified by a set of equations which describe the behaviour of vechiles.

Over the years a number of analytical models have been developed to obtain delay and queue length at unsignalized intersections. One of the earliest theoretical model for unsigalized intersection was developed by Adams'[1] in 1936, in which a problem of pedestrians delay at unsignalized intersections was studied and several relationships to determine average delay were derived (Note the model can also be applied to vehicle delay).

Tanner [2] extended the work of Adams by considering a more general gap acceptance criterion. Heidemann [3] extended Tanner's mean queue length and mean delay formulas to yield formula for a corresponding distribution. It may be noted that these models assumed that one stream always had the right-of-way as a reasonably strong simplifying assumption.

A more general study of four way stop-sign intersection capacity was studied by Herbert [4]. He examined the characteristics of the traffic at a limited number of multi-way stop-sign intersections and from these observations, obtained estimates of intersection capacity at multi-way stop-sign intersections under a range of traffic distribution assumptions. However, although Herbert's conclusion on intersection capacity are useful, he makes no attempt to specify how the intersection performs in terms of delays experienced in the traffic volume range between zero flow and capacity.

Richardson [5] reported an analytical model of delays experienced at multi-way stop-sign intersection. Delays at multi-way stop-sign are shown to be the result of a set of complex interactions between the flows on all approaches to the intersection. Influences on the delays are due to flow on

that approach, flow on conflicting approach and flow on opposite approaches. Richardson's model shows good agreement in terms of capacities and level of service for various demand split. However, this model, as used in the network equlibrium program, assumes no turning flows. Which is an important factor in Indian conditions that hinder the proceedings in the intersection.

Although the analytical models provide in sight into the functioning of an unsignalized intersection, one necessarily has to make simplifying assumptions about arrival, queuing, and dissipation inorder to keep the formulation tractable. Further, under Indian conditions, certain characteristics like vehicle mix, lack of traffic discipline, etc., make these analytical models extremely poor representatives of the reality.

The drawbacks of analytical models presented first was enough motivation for researchers to try and develop simulation models of unsignalized intersections.

3.3 Simulation Models

Kell [6] developed a simulation model for the intersection of a pair of 2-lane two-directional streets. The model was developed for analyzing both 2-way stop and signal control. A vehicle generation method and gap acceptance distribution are also presented.

Kikurchi and Chakroborthy [7], has analyzed the criteria that should be considered when justifying a left-turn lane (i.e. right-turn lane in the Indian road context) on the major approach of an unsignalized T-intersection. A simulation model of the movements of the vehicles on the approach is developed, and delays to through vehicles with and without a left-turn lane for different traffic volumes are computed. Further more, a set of regression equations is

developed that represents delay to the through vehicles and delay savings. A computation procedure for the level of service on a shared lane approach to an unsignalized T-intersection is examined.

Although these simulation models were an improvement over the analytical models they are not suitable for Indian conditions primarily because:
(i) large variety of vehicles
(ii) queuing at the middle of the intersection, and
(iii) arbitrary and risk-taking movement in order to gain control of the right-of-way.

Chapter 4

DEVELOPMENT AND IMPLEMENTATION OF THE SIMULATION MODEL

In this chapter, the simulation model for unsignalized intersections in India conditions is described in detail. First, the overall logic used in simulating th intersection is described. Later, the model assumptions, inputs and output are presented. This is followed by a detailed description of the implementatio of the proposed simulation model.

4.1 Logic

In order to achieve realism in modeling Indian unsignalized intersections, th unsignalized intersection is visualized as having eight decision points; points a which vehicles come and decide whether to proceed further or not dependin on gap availability. Figure 4.1 schematically represents the present visualiza tion of an Indian unsignalized intersection. As explained in the chapter o "Problem Statement", vehicles come and join the queues at these decisio points depending on their movements.

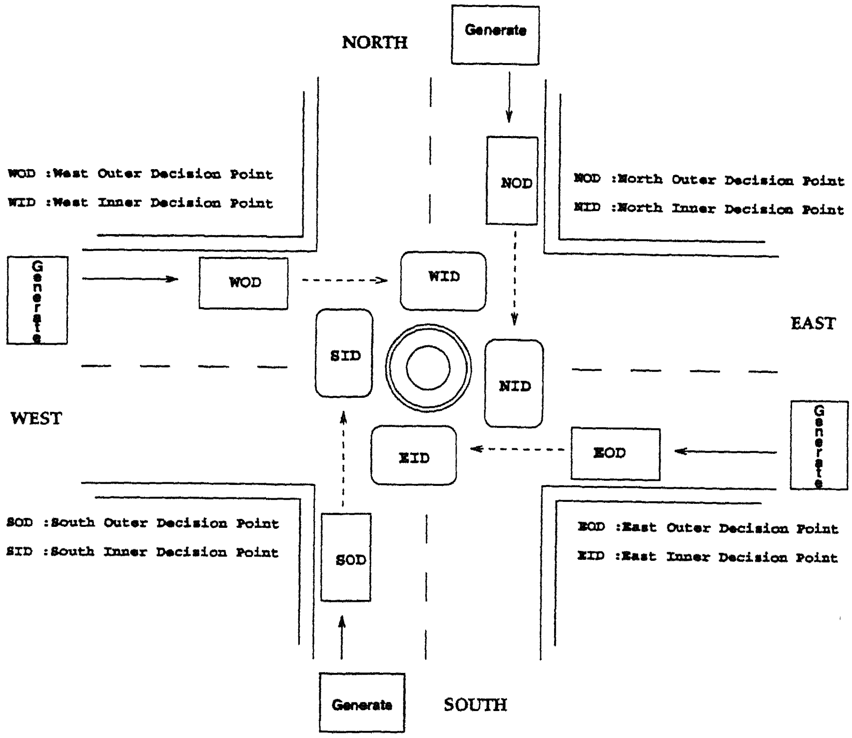


Figure 4.1: Unsignalized intersection view to explain the logic

At these decision points, one of two things happen: (i) the vehicle at the top of the queue looks for a gap in the opposing stream and on finding an adequate gap leaves the decision point; or (ii) the vehicle at the top of the queue decides to depart on seeing that the vehicle on the opposing stream is stopped (for example, a vehicle at SOD may depart if it sees that the vehicle at EID is stopped). When the vehicle departs, as with any queuing system the next vehicle in the queue moves to the top of the queue. This process continues.

The above paragraph describe the logic of vehicle movements used in the present simulation model. The following sections describe in detail the various features of the simulation model.

4.2 Model assumptions

The assumptions made in constructing the model can be briefly summarized as :

1) All vehicles will move in queue and move to front of queue through a self made lane.

2) Time taken to reach from an outer decision point to the relevant inner decision point is taken to be 2 seconds. (This time can be easily changed if data is available.)

3) The mathematical distribution to describe the inter-arrival time of vehicles in a traffic stream is assumed to be negative exponential distribution. (The model can easily incorporate any other distribution.)

4) The gap acceptance behaviour at a decision point is assumed to vary with vehicle type only. Further, gap acceptance is considered to be probabilistic with the probability of accepting a gap varying with the size of the gap.

5) The road is assumed to be of uniform cross section.

6) The terrain is considered flat, the vehicles hence have adequate sight distance.

7) Vehicle type and movement for a vehicle in a stream are decided randomly. The probability of a vehicle being of a particular type and movement obviously depends on the proportion of such vehicles and movements in that stream.

4.3 Model inputs

The simulation model, as implemented, requires the following input data:

1) Total simulation time.

2) Seed values for the different random number generators required for vehicle generation, assigning vehicle type and movement, gap acceptance etc.

3) The mean time headway of vehicles in different streams.

4) The proportions of different types and movements of vehicles in a traffic stream.

4.4 Model outputs

The traffic system is simulated by using fixed-increment time advance approach of discrete-event simulation model. In this every decision point is scanned at every second to build an event file during the simulated period and a final output file at the end of the simulation period. The event file gives the identification number of the vehicle, turning movement, its type, arrival time, departure time and delays at the outer and inner decision points. The final output file prints the average queue lengths, average delays at all decision points in all directions and total average delay in all directions. A portion of an event file and output file is shown below.

```
EVENT FILE:
-------------------------------------------------------------------

TMVT = Turning movement of the veh.
AODP = Arrival time of the veh. to outer decision point
TODP = Arrival time of the veh. to top of the queue in ODP
DODP = Departure time of the veh. from outer decision point
dODP = Delay to the veh. in outer decision point
AIDP = Arrival time of the veh. to inner decision point
TIDP = Arrival time of the veh. to top of the queue in IDP
DIDP = Departure time of the veh. from inner decision point
dIDP = Delay to the veh. in inner decision point
TDLY = Total delay to the veh.
```

VehID	TMVT	TYPE	AODP	TODP	DODP	dODP	AIDP	TIDP	DIDP	dl	
10001	left	scooter	2.05	2.05	3.00	0.95	0.00	0.00	0.00	0.00	0.95
10004	left	car	5.24	7.00	8.00	2.76	0.00	0.00	0.00	0.00	2.76
10010	left	car	16.00	16.00	17.00	1.00	0.00	0.00	0.00	0.00	1.00
10012	left	car	20.52	20.52	21.00	0.48	0.00	0.00	0.00	0.00	0.48
10013	left	car	27.34	27.34	30.00	2.66	0.00	0.00	0.00	0.00	2.66
10018	left	car	38.13	38.13	40.00	1.87	0.00	0.00	0.00	0.00	1.87
10034	left	car	84.54	84.54	85.00	0.46	0.00	0.00	0.00	0.00	0.46
10036	left	car	89.04	89.04	90.00	0.96	0.00	0.00	0.00	0.00	0.96
10037	left	car	91.64	91.64	92.00	0.36	0.00	0.00	0.00	0.00	0.36
10040	left	car	97.42	99.00	100.00	2.58	0.00	0.00	0.00	0.00	2.58
10002	through	car	3.20	3.20	6.00	2.80	8.00	8.00	12.00	4.00	8.80
10005	through	car	6.91	8.00	10.00	3.09	12.00	13.00	14.00	2.00	7.09
10008	through	scooter	10.82	14.00	15.00	4.18	17.00	17.00	17.00	0.00	6.18
10009	through	car	13.22	15.00	16.00	2.78	18.00	18.00	18.00	0.00	4.78
10011	through	car	16.64	17.00	18.00	1.36	20.00	20.00	24.00	4.00	7.36
10014	through	car	28.20	30.00	32.00	3.80	34.00	34.00	34.00	0.00	5.80
10017	through	car	34.43	34.43	35.00	0.57	37.00	37.00	42.00	5.00	7.57
10019	through	scooter	40.41	40.41	44.00	3.59	46.00	46.00	46.00	0.00	5.59
10020	through	car	41.06	44.00	45.00	3.94	47.00	47.00	47.00	0.00	5.94
10021	through	scooter	43.79	45.00	46.00	2.21	48.00	48.00	48.00	0.00	4.21
10003	right	scooter	3.97	6.00	7.00	3.03	9.00	14.00	15.00	6.00	11.03
10006	right	scooter	8.49	10.00	13.00	4.51	15.00	15.00	19.00	4.00	10.51
10007	right	car	9.25	13.00	14.00	4.75	16.00	19.00	20.00	4.00	10.75
10015	right	scooter	29.08	32.00	33.00	3.92	35.00	35.00	36.00	1.00	6.92
10016	right	scooter	29.99	33.00	34.00	4.01	36.00	36.00	37.00	1.00	7.01

10025	right	car	54.89	55.00	56.00	1.11	58.00	58.00	59.00	1.00	4.11
10027	right	scooter	56.45	57.00	58.00	1.55	60.00	70.00	71.00	11.00	14.55
10031	right	car	70.32	70.32	75.00	4.68	77.00	77.00	77.00	0.00	6.68
10032	right	car	74.96	75.00	76.00	1.04	78.00	78.00	78.00	0.00	3.04
10035	right	car	84.68	85.00	87.00	2.32	89.00	89.00	91.00	2.00	6.32

=======================================

FINAL OUTPUT FILE:

```
*********************************************
*                   RESULTS                 *
*********************************************
*-------—SIMULATION TIME = 3600.00 Seconds—------*
------------------------------------------------
```

Input data:-

		Proportion of Turning movements		
DIRECTION	FLOW (Veh/hr)	LEFT	RIGHT	THROUGH
NORTH	1500.00	30.00%	20.00%	50.00%
SOUTH	1000.00	30.00%	10.00%	60.00%
EAST	1000.00	30.00%	10.00%	60.00%
WEST	1000.00	30.00%	10.00%	60.00%

Vehicle Type and Mix in each Direction

NORTH	Veh Type	Percentage
	scooter	20.00%
	truck	10.00%
	car	70.00%
SOUTH	Veh Type	Percentage
	scooter	40.00%
	truck	10.00%
	car	50.00%

EAST	Veh Type	Percentage
	scooter	40.00%
	bus	10.00%
	car	50.00%
WEST	Veh Type	Percentage
	motorcycle	30.00%
	bus	10.00%
	car	60.00%

Output data:-

Avg. queue length at NOD=0.930000

Avg. queue length at NID=1.640278

Avg. queue length at SOD=0.343056

Avg. queue length at SID=0.798056

Avg. queue length at EOD=0.917778

Avg. queue length at EID=1.310556

Avg. queue length at WOD=0.215833

Avg. queue length at WID=0.824722

Avg.delay to LEFT turning veh. at NOD=2.775811

Avg.delay to LEFT turning veh. at SOD=1.631879

Avg.delay to LEFT turning veh. at EOD=3.971611

Avg.delay to LEFT turning veh. at WOD=1.270733

Avg.delay to RIGHT turning veh. at NOD=3.022324

Avg.delay to RIGHT turning veh. at SOD=1.885135

Avg.delay to RIGHT turning veh. at EOD=3.409925

Avg.delay to RIGHT turning veh. at WOD=1.138252

Avg.delay to THROUGH veh. at NOD=2.513602

Avg.delay to THROUGH veh. at SOD=1.761885

Avg.delay to THROUGH veh. at EOD=3.444582

Avg.delay to THROUGH veh. at WOD=1.357911

Avg.dly to NORTH,Lt veh. after crossing X'n=2.775811

Avg.dly to SOUTH,Lt veh. after crossing X'n=1.631879

Avg.dly to EAST ,Lt veh. after crossing X'n=3.971611

Avg.dly to WEST ,Lt veh. after crossing X'n=1.270733

Avg.dly to NORTH,Rt veh. after crossing X'n=11.907675

Avg.dly to SOUTH,Rt veh. after crossing X'n=8.317567

Avg.dly to EAST ,Rt veh. after crossing X'n=11.186046

Avg.dly to WEST ,Rt veh. after crossing X'n=9.817863

Avg.dly to NORTH,Th veh. after crossing X'n=7.761283

Avg.dly to SOUTH,Th veh. after crossing X'n=5.407047

Avg.dly to EAST ,Th veh. after crossing X'n=8.150661

Avg.dly to WEST ,Th veh. after crossing X'n=5.329595

Avg.delay to NORTH dir veh. at OD point=8.311737

Avg.delay to SOUTH dir veh. at OD point=5.278899

Avg.delay to EAST dir veh. at OD point=10.826118

Avg.delay to WEST dir veh. at OD point=3.766897

Avg.dly to NORTH dir veh. after crossing X'n=22.444769

Avg.dly to SOUTH dir veh. after crossing X'n=15.356493

Avg.dly to EAST dir veh. after crossing X'n=23.308315

Avg.dly to WEST dir veh. after crossing X'n=16.418190

4.5 Model Formulation and Implementation

The model has been formulated and implemented through the following procedures which are coordinated through a main program.

- Vehicle arrival Procedure
- Gap acceptance Procedure
- Vehicle queuing Procedure
- Delete Procedure
- Outer decision point Procedure
- Inner decision point Procedure

4.5.1 Vehicle arrival procedure

In India heterogeneity in traffic conditions is a common phenomenon. On a road, vehicles like trucks, buses, cars, two-wheelers, etc move in both directions. Hence, the procedure to simulate vehicle arrivals must be versatile enough to accommodate all types of vehicles in the traffic stream. The procedure used here is as follows:
(i) Given the volume of the traffic stream being simulated, random numbers denoting inter-arrival times of vehicles are generated. From the random inter-arrival times thus generated the arrival times of the vehicles are obtained. Various different distributions can be used to obtain the random numbers for the inter-arrival times. In this study, however, the negative exponential distribution is used.

The subprogram "expon" generates an exponential random variable with MEAN, which will be given as input. The program begins by obtaining a random variable U which is uniformly distributed on the interval 0 to 1. The U(0,1) random variable has the following probability density function:

$$f(x) = \begin{cases} 1 & \text{if } 0 \leq x \leq 1 \\ 0 & \text{otherwise} \end{cases}$$

The U(0,1) random variable is fundamental to simulation modeling because, any random variable of interest can be generated by first generating one or more U(0,1) random variables. The U(0,1) random variable U was generated in our program by calling another subprogram "Ran1" for which code was taken from "Numerical recipes in C" [8]. To generate an exponential random variable with MEAN, the natural logarithm (ln) of the U(0,1) random variable U is taken and multiplied by the negative of the value of MEAN. (Papacosta, 1987) [9] and (A.D. May, 1990) [10].

(ii) Once the arrival times of vehicles of each stream are obtained, the task is to assign type and movement to each vehicle randomly and independently. For this purpose two more uniform random number lists are generated and used to assign type and movement. Obviously, the assignment of type and movement depends on the input proportions of both in the traffic stream. For example, if a traffic stream has 20 % two-wheelers, 50 % cars and 30 % trucks; 40 % of all vehicles are through vehicles, 25 % are left-turning and 35 % are right-turning vehicles; and let U1 and U2 be the sets of random numbers used for assigning vehicle type and movement respectively. Then, if for a particular vehicle U1 lies in [0,0.2] then the type assigned to the vehicle is two-wheeler, if it is between 0.2 and 0.7 then it is a car else it is a truck. Similarly, if for the same vehicle U2 is in the range 0 to 0.4 then it is a through vehicle, if it is in the range 0.4 to 0.65 then it is a left-turning vehicle else a right-turning vehicle.

A flow chart for vehicle arrival procedure is shown in Fig.4.2.

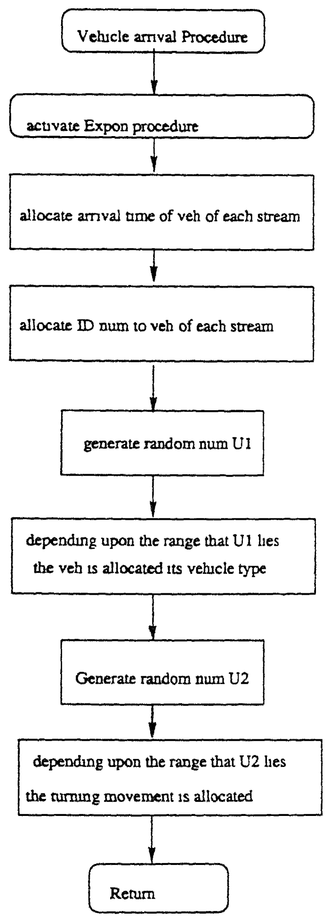
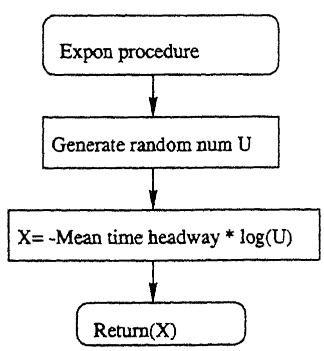


Figure 4.2: Flow chart for subprogram Vehicle arrival.



4.5.2 Gap acceptance procedure

Once the vehicle reaches the intersection, it stops, and the driver scans the traffic in the conflicting stream. The waiting driver selects a "suitable" gap in the conflicting traffic stream to proceed and join another decision point or leave the intersection. The gap available to the driver at any time is calculated as the difference between the arrival time of the vehicle in the conflicting stream at its decision point and the arrival time of the vehicle looking for a gap at its decision point. Whether the available gap is "suitable" (accepted) is decided using a probabilistic acceptance rule. The specific acceptance criteria used here is explained through Fig. 4.3.

As shown in the figure, a relationship between available gap size and the

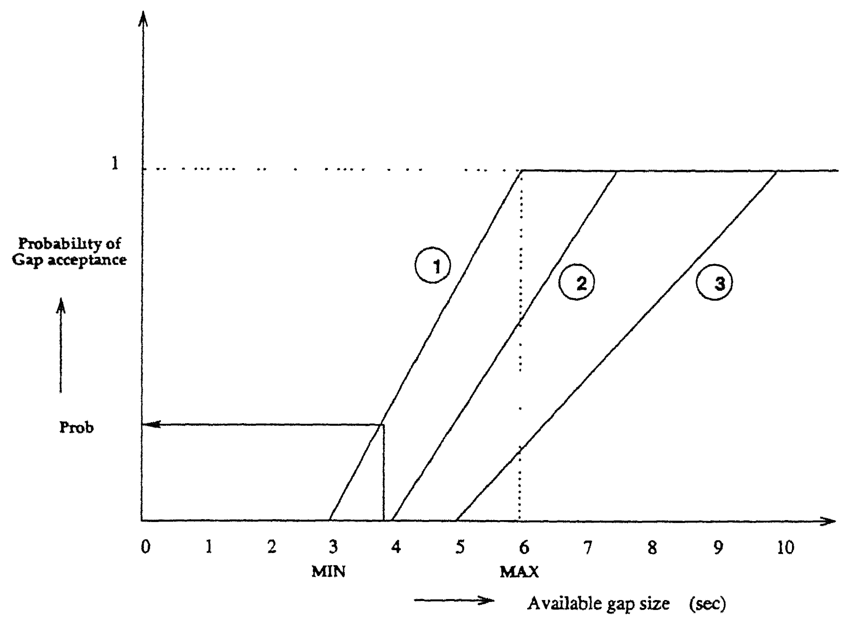


Figure 4.3: Sketch showing Gap acceptance criteria

probability that the gap is accepted is assumed as the criterion for gap acceptance. The relationships are such that all gaps beyond a certain maximum size (for example 6 sec for line-1) are accepted while all gaps below a certain minimum size (for example 3 sec for line-1) are rejected. In between the min-

imum and maximum size the gaps are acceptable with a certain probability. In the present size, the probability is assumed to increase linearly from the zero at minimum size to 1 at maximum size. Further three different relationships are assumed, line-1 is for two-wheelers (scooter/motorcycle), line-2 is for automobiles (car/jeep) and line-3 is for heavy vehicles (bus/truck).

In addition to above gap acceptance criteria some tie-breaking criteria are also assumed. These are explained as follows:

Case(i): When vehicles in both ODP and the conflicting IDP arrive to the top of the queue at around the same time, then conflict occurs as to which vehicle should move first. This conflicting condition is resolved by assigning 50 percent probability of first movement to ODP vehicle and 50 percent probability of first movement to IDP vehicle. Now a uniformly distributed random number is generated between 0,1 and if random number turns out to be less than or equal to 0.5 then ODP vehicle is moved first, otherwise IDP vehicle is allowed to move first.

Case(ii): If the arrival time of the ODP vehicle which had reached the top of the queue is two second earlier (or any other suitable threshold value) than the arrival time of the IDP vehicle which has reached the top of the queue and if the available gap between these two vehicles has been already rejected once by the ODP vehicle then a probability of 60 percent of first movement is assigned to ODP vehicle and a probability of 40 percent of first movement is assigned to IDP vehicle to accept a gap. Again a uniformly distributed random number is generated between 0,1 and if random number turns out to be greater than 0.4 then ODP vehicle is moved first, otherwise IDP vehicle is moved.

Case(iii): If the arrival time of the ODP vehicle which had reached the top of the queue is three second earlier (or any other suitable threshold value) than the arrival time of the IDP vehicle which has reached the top of the queue and if the available gap between these two vehicles has been already rejected once by the ODP vehicle, then a probability of 70 percent of first movement

is assigned to ODP vehicle and a probability of 30 percent of first movement is assigned to IDP vehicle to accept a gap. Again a uniformly distributed random number is generated between 0,1 and if random number turns out to be greater than 0.3 then ODP vehicle is moved first, otherwise IDP vehicle is moved.

Similar criteria are applied repetitively at all eight decision points. A flow chart for gap acceptance procedure is shown in Fig.4.4.

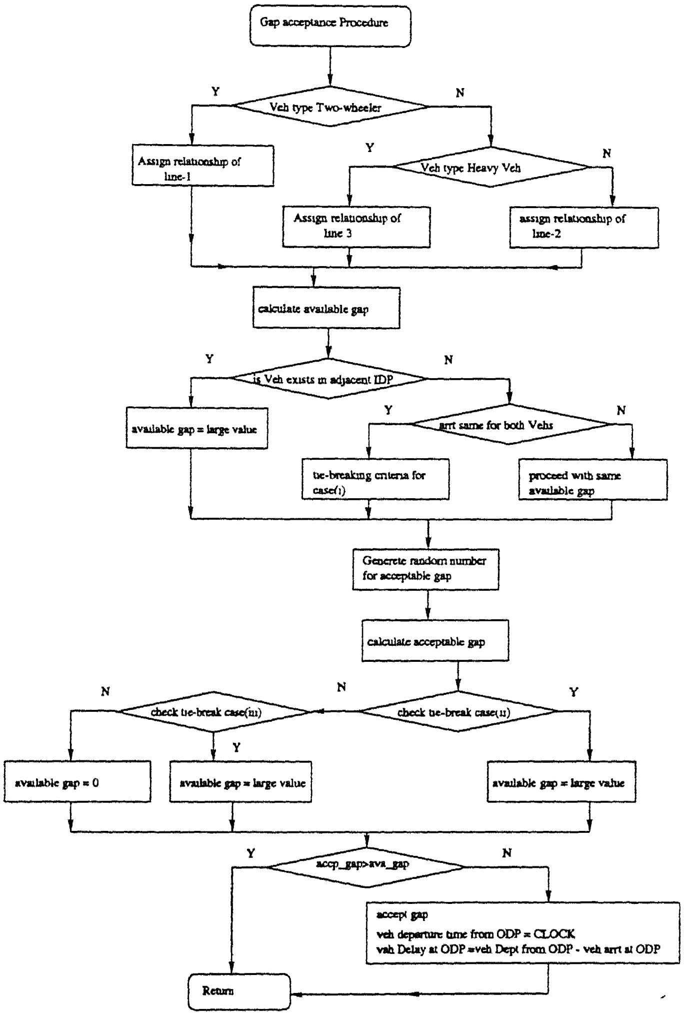
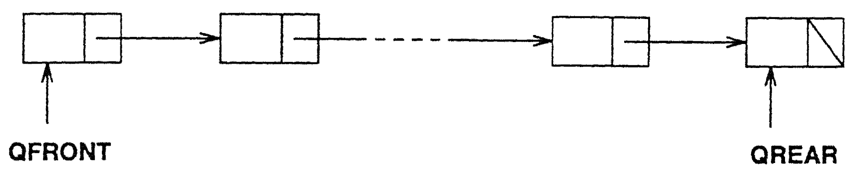


Figure 4.4: Flow chart for subprogram gap acceptance.

4.5.3 Queue length procedure

When a vehicle arrives at a decision point and finds another vehicle waiting there it waits after that, forming a queue. The basic queuing model used was an M/G/1 model (negative exponential arrival rates, general distribution of service rates and a single server). A queue is an ordered group of elements in which new elements are added at one end (the rear) and elements are removed at the other end (the front). A queue can be implemented in a linked list by keeping two external pointers to the list. One to the node on each end. The FIFO (first in, first out) data structure is used here to represent the queue. We can access the front of the queue through the pointer QFRONT and the rear of the queue through QREAR (Nell Dale, 1995) [11].



A flow chart for procedure queue length is shown in Fig.4.5.

4.5.4 Delete procedure

At a decision point if the vehicle at the top of the queue finds a suitable available gap in the conflicting traffic stream, it will take a decision to move out of that corresponding decision point. That is it will leave the queue. This task is performed by calling the delete subprogram. A flow chart for delete procedure is shown in Fig. 4.6.

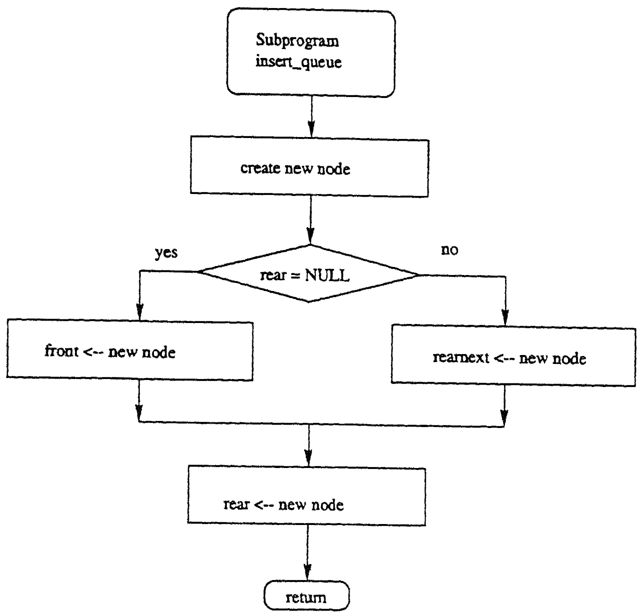


Figure 4.5: Flow chart for subprogram queue length.

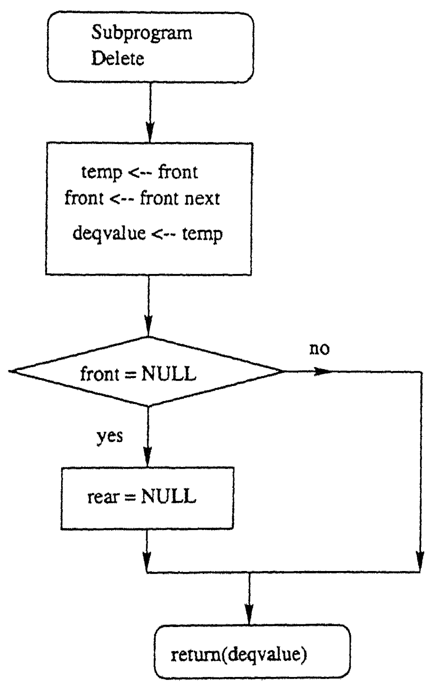


Figure 4.6: Flow chart for subprogram delete.

4.5.5 Outer decision point procedure

These are the decision points, which are assumed to be existing at the nose of the intersection approach. When a vehicle arrives at the outer decision point; it will check whether the queue at that point empty, if it is empty then the ODP procedure activates the gap acceptance procedure. If not it activates the vehicle queuing procedure. Once the gap acceptance procedure returns with acceptable gap then depending on the vehicle turning movement, the vehicle is either taken out of the system or passed on to the relavent IDP. The logic of the procedure can be best explained by the flow chart shown in the Fig. 4.7.

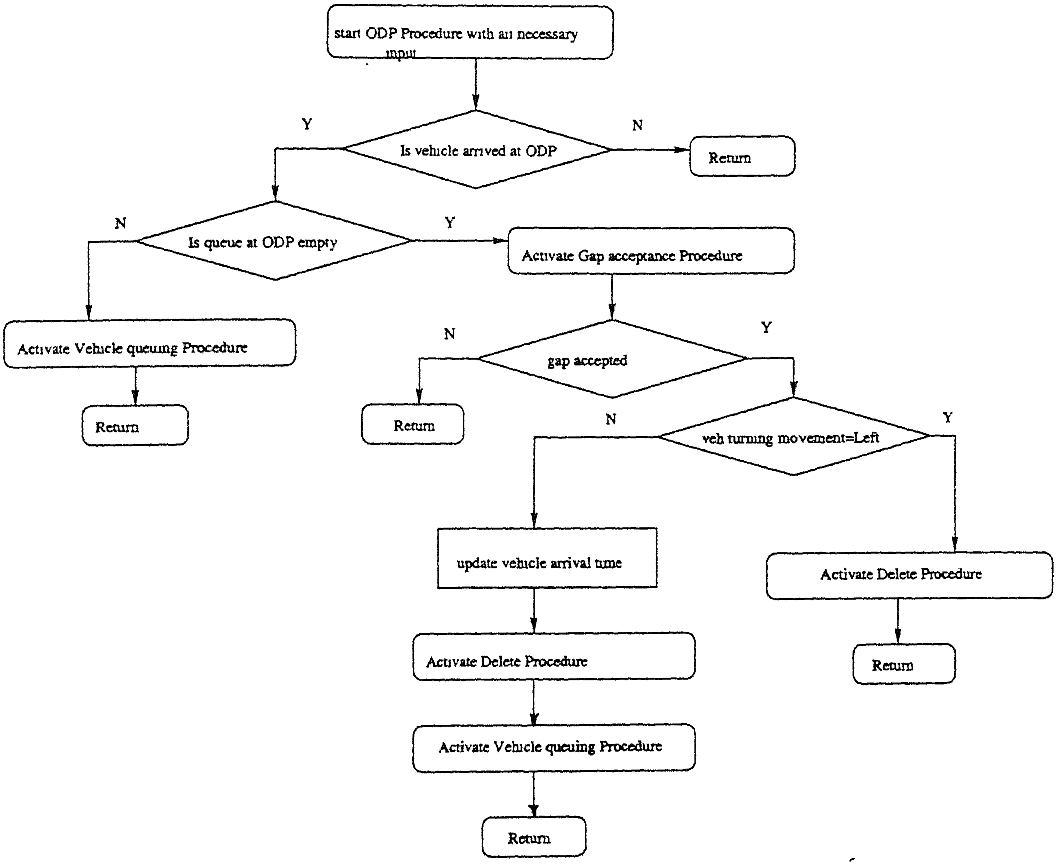


Figure 4.7: Flow chart for subprogram Outer Decision Point.

4.5.6 Inner decision point procedure

These are the decision points, which are assumed to be existing at the middle of the intersection. When a vehicle arrives at the inner decision point; it will check whether the queue at that point empty, if it is empty then the IDP procedure activates the gap acceptance procedure. If not it activates the vehicle queuing procedure. Once the gap acceptance procedure returns with acceptable gap then depending on the vehicle turning movement, through vehicles will take a decision to move out of the intersection and the right turning vehicles will join in the next inner decision point. The logic of the procedure can be best explained by the flow chart shown in the Fig. 4.8.

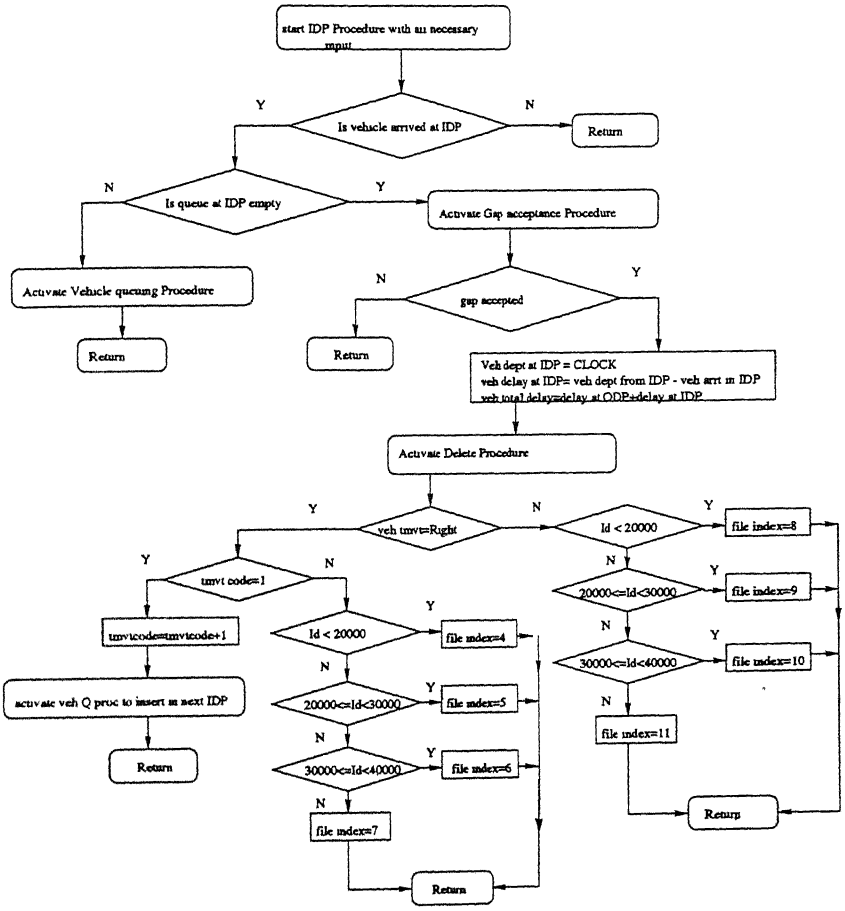


Figure 4.8: Flow chart for subprogram Inner Decision Point.

The general nature of the model can be best explained by flow chart given in Fig. 4.9. The flow chart depicts pictorially the sequence in which instructions are carried out in model.

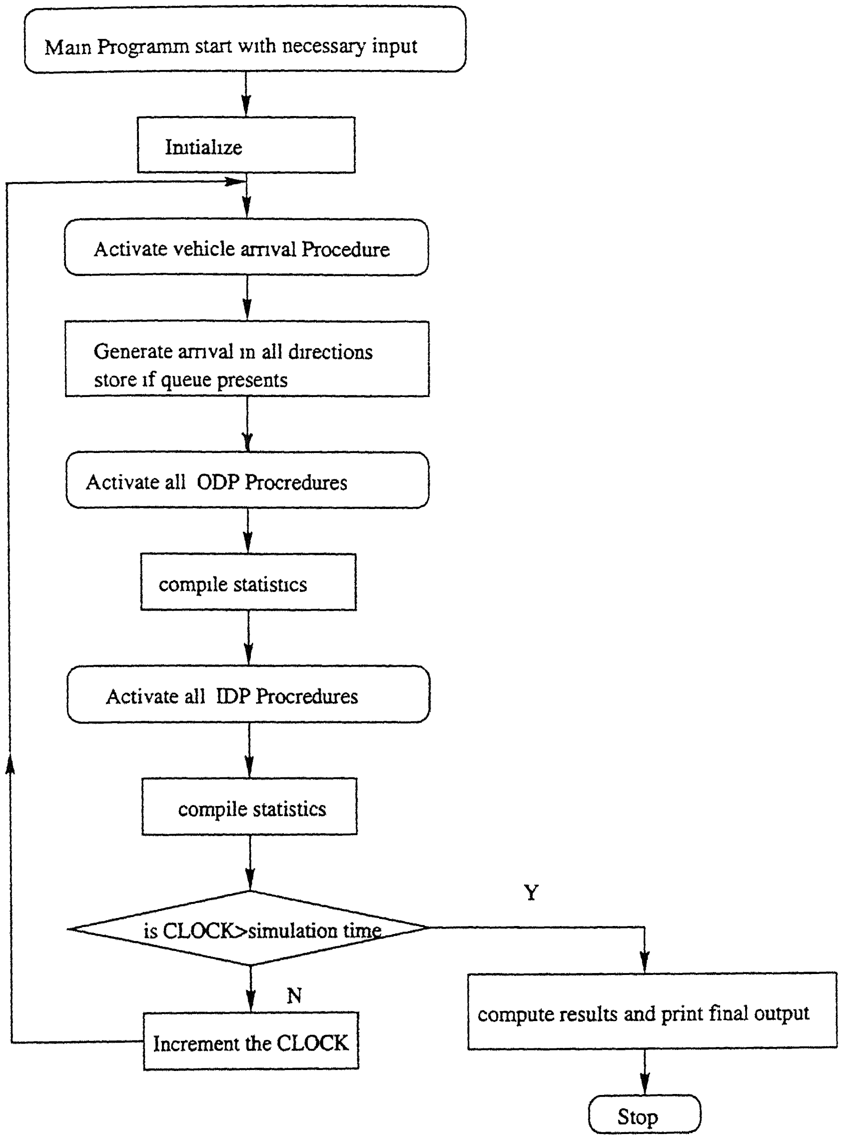


Figure 4.9: Flow chart for Main program.

Chapter 5

RESULTS AND DISCUSSION

In this chapter we present the results obtain from the proposed simulation model. The chapter is divided into two major sections. In the first section we present results which illustrate the capability of the proposed model to provide results on all the six points mentioned below:

(1) Delays at each decision point for every vehicle.
(2) Delay distributions at every decision point.
(3) Average delay at each decision point.
(4) Queue length at each decision point.
(5) Queue length distribution at each decision point.
(6) Average queue length at each decision point.

The second section concentrates on providing preliminary results from sensitivity analysis of average delay and average queue length with respective to the following parameters.

(1) Volume of traffic.
(2) Proportion of turning movement and
(3) Vehicle mix (Proportion of different types of vehicles).

5.1 Capability of the proposed model

Table 5.1. shows a portion of a typical output file which gives details on the delay to each vehicle. In the table Vehi-Id represent the vehicle identification number for the corresponding direction, Tmvt represent its turning movement, Type represent the vehicle type, dODP represent the delay to the vehicle at outer decision point, dIDP represent the delay to the vehicle at inner decision point and Tdly represent the total delay to the vehicle in the corresponding direction.

Table 5.1: A portion of a typical output file which gives details on the delay to each vehicle.

Veh-Id	Tmvt	Type	dODP (sec)	dIDP (sec)	Tdly (sec)
10001	left	scooter	0.95	0.00	0.95
10004	left	car	2.76	0.00	2.76
10010	left	car	1.00	0.00	1.00
10012	left	car	0.48	0.00	0.48
10013	left	car	2.66	0.00	2.66
10018	left	car	1.87	0.00	1.87
10002	through	car	2.80	4.00	8.80
10005	through	car	3.09	2.00	7.09
10008	through	scooter	4.18	0.00	6.18
10009	through	car	2.78	0.00	4.78
10011	through	car	1.36	4.00	7.36
10003	right	scooter	3.03	6.00	11.03
10006	right	scooter	4.51	4.00	10.51
10007	right	car	4.75	4.00	10.75
10015	right	scooter	3.92	1.00	6.92
10016	right	scooter	4.01	1.00	7.01

Table 5.1. is an output file obtained for the simulation run of a particular case with following details:

		Proportion of Turning movements		
DIRECTION	*FLOW(Veh/hr)*	*LEFT*	*RIGHT*	*THROUGH*
NORTH	1500.00	30%	20%	50%
SOUTH	1000.00	30%	10%	60%
EAST	1000.00	30%	10%	60%
WEST	1000.00	30%	10%	60%

Vehicle Type and Mix in each Direction

NORTH	*VehType*	*Percentage*
	scooter	20%
	truck	10%
	car	70%
SOUTH	*VehType*	*Percentage*
	scooter	40%
	truck	10%
	car	50%
EAST	*VehType*	*Percentage*
	scooter	40%
	bus	10%
	car	50%
WEST	*VehType*	*Percentage*
	motorcycle	30%
	bus	10%
	car	60%

Figure 5.1. through 5.6. illustrate the fact that the proposed model can give delay distributions to vehicles in each of the directions. These figures are however plotted for total delay to vehicles coming from the north and for vehicles coming from the south. The ordinate in the figures represent relative frequency and the abscissa represents delays in 1 second class intervals. For example from figure 5.1. it can be seen that approximately 20 % of the vehicles were delayed between 1 and 2 seconds. All the figures are plotted for following details in all four directions.

i) Volume of the traffic flow : 1000 veh/hr.

ii) Proportion of turning movements : 20% left, 20% right, 60% through.

iii) Proportion of vehicle mix : 0% Two-wheeler, 0% Heavy-vehicle, 100% Automobile.

As can be seen, corresponding figures for vehicles coming from the north

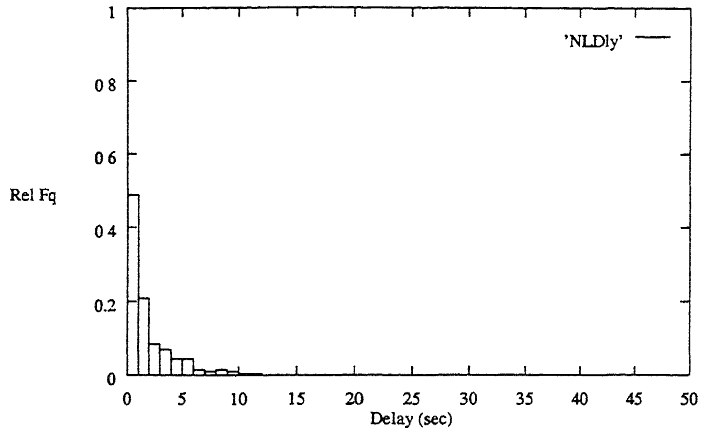


Figure 5.1: Total Delay distribution for NORTH Left turning vehicles

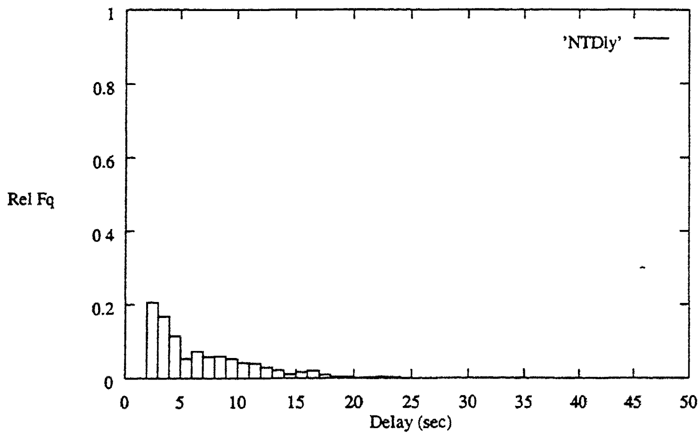


Figure 5.2: Total Delay distribution for NORTH Through vehicles

and from the south (example, figure 5.1 and 5.4, 5.2 and 5.5 and, 5.3 and 5.6) are more or less equivalent. This is expected since volume, vehicle mix and turning proportion are same in both directions. Similar figures can also be plotted for the vehicles coming from the east as well as west. But are not provided here as they do not illustrate any thing more than what has been already illustrated.

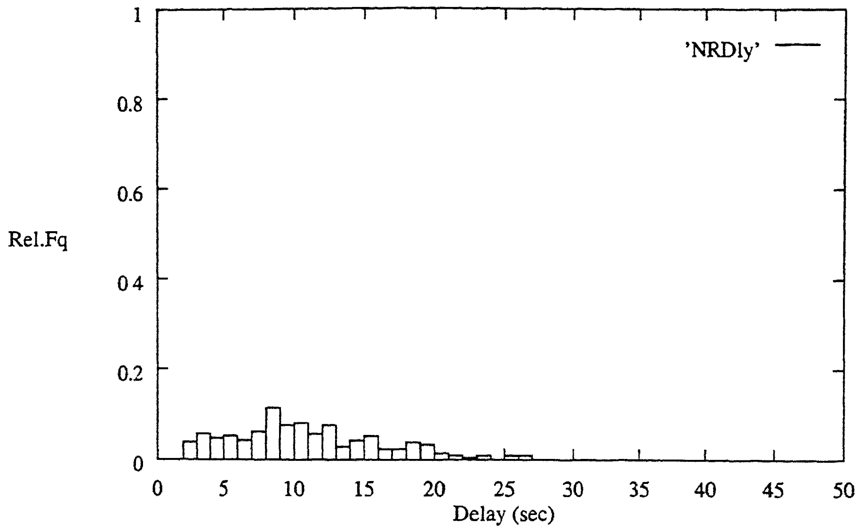


Figure 5.3: Total Delay distribution for NORTH Right turning vehicles

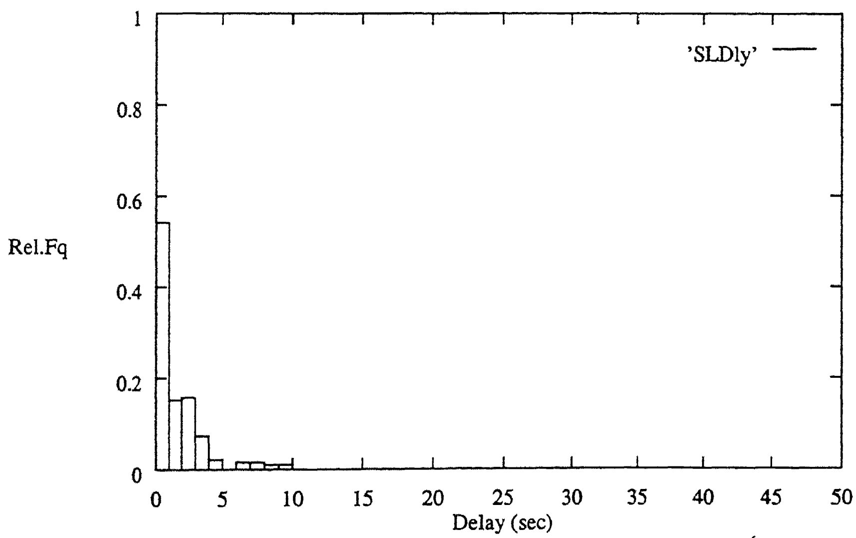


Figure 5.4: Total Delay distribution for SOUTH Left turning vehicles

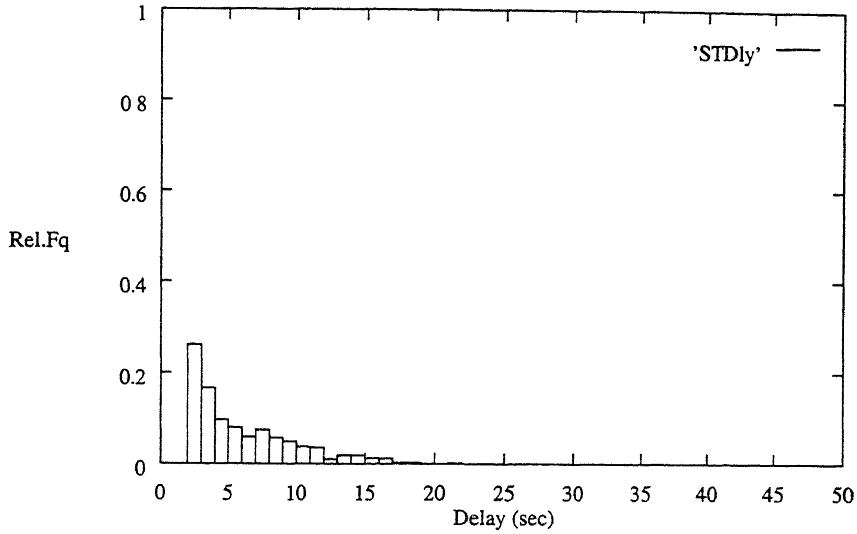


Figure 5.5: Total Delay distribution for SOUTH Through vehicles

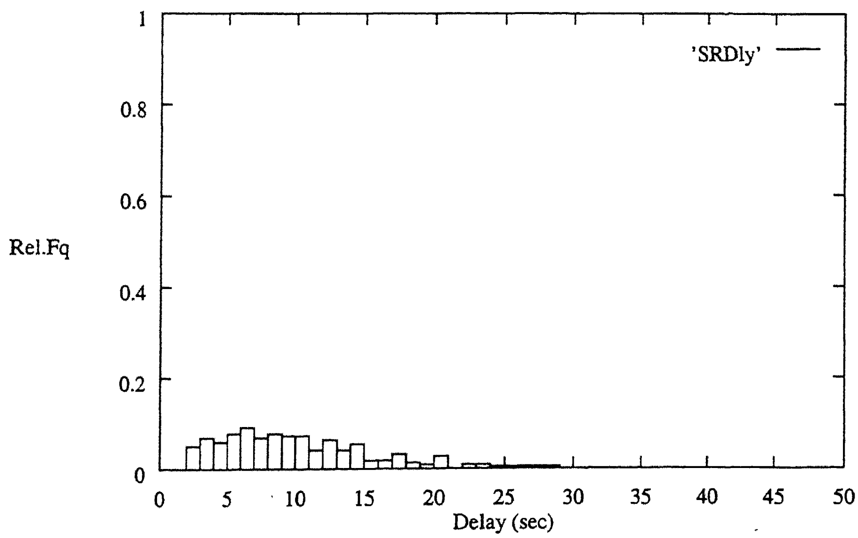


Figure 5.6: Total Delay distribution for SOUTH Right turning vehicles

It is obvious that one can obtain results on average delay from the above type of outputs. Hence results are not provided to illustrate this fact.

Table 5.2. shows a portion of a typical output file which gives details on the queue length at each decision point at every second. In the table Q1 represent the queue length at north outer decision point and Q2 represent the queue length at north inner decision point. Similar output results can also be obtained for other three directions, but are not provided here.Table 5.2. is an output file obtained for following details in all four directions.

i) Volume of traffic flow : 1500 veh/hr.

ii) Proportion of turning movement : 0% left, 0% right, 100% through,

iii) Proportion of vehicle mix : 0% Two-wheeler, 0% Heavy-vehicle, 100% Automobile.

Table 5.2: A portion of a typical output file which gives details on the queue length at each decision point.

Time (sec)	Q1	Q2
1.00	0	0
2.00	0	0
3.00	0	1
4.00	2	1
5.00	1	1
6.00	2	1
7.00	2	1
8.00	2	1
9.00	2	1
10.00	2	2
11.00	2	2
12.00	2	2
13.00	1	3
14.00	2	2
15.00	2	1
16.00	3	0

Figure 5.7. and 5.8. shows the queue length distribution at north outer decision point and south outer decision point respectively. These figures are plotted for following details in all the four directions.

i) Volume of the traffic flow : 1000 veh/hr.

ii) Proportion of turning movements : 20% left, 20% right, 60% through.

iii) Proportion of vehicle mix : 0% Two-wheeler, 0% Heavy-vehicle, 100% Automobile.

Similar figures can also be plotted for inner decision points. Obviously one

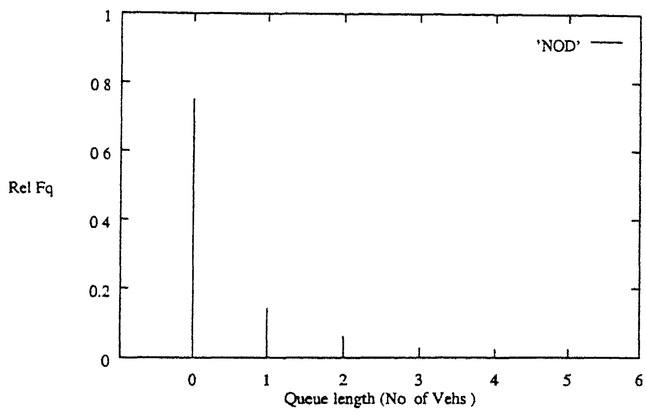


Figure 5.7: Queue length distribution for NORTH Outer Decision Point

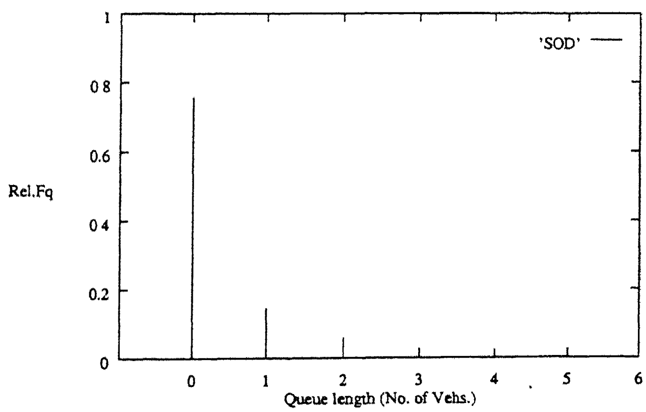


Figure 5.8: Queue length distribution for SOUTH Outer Decision Point

can compute average queue length from the above type of output that can be obtained here.

5.2 Sensitivity analysis

In this section the sensitivity of the results with respect to the percentages of left-turn, right-turn and through vehicles as well as with respect to vehicle mix are presented. Table 5.3. shows the queue lengths at outer (Q1) and inner (Q2) decision points for vehicles coming from the north. It also shows the delay at the outer decision point (D1) and the total delay (D2) for vehicles coming from the north. Different volume conditions and percentages of left-turn, right-turn and through vehicles for vehicles coming from the north are considered. Further three different volume conditions for the other three directions are also considered.

The results show expected trends in queue length and delay. For example when left-turning percentage increases from 0 to 80 the queue lengths Q1 and Q2 as well as delays D1 and D2 reduce. This is as expected because left-turning movements are much easier to make (as they merge into the conflicting stream) than through movements. Reasonably opposite trends are shown when right-turning percentages increase. This is also expected as right-turning movements are more difficult than through movements.

Table 5.4. shows results from the sensitivity analysis of queue length and delays with respect to different vehicle mixes. Here three different volume conditions are considered for vehicles coming from the north while the volume in other three directions are kept at 1000 veh/hr in each direction. The results show expected trends. For example the queue length Q1 and Q2 as well as the delays D1 and D2 decrease when the percentage of two-wheelers in the traffic stream increase. Opposite trend is shown when the percentage of heavy vehicles increase in the traffic stream.

Table 5.3: Results from the sensitivity analysis for 100% automobile and different turning movement proportion.

Sl.No.	Tmvt percent			Vol in S,E,W	Vol in North	Avg.Q-len.		Avg.Delay	
	Lt	Rt	Th	Veh/hr	dir.Veh/hr	Q1	Q2	D1	D2
1	0	0	100	500	500	0.05	0.48	1.89	4.79
					1000	0.24	1.13	1.38	5.42
					1500	1.16	2.05	3.25	8.12
				1000	500	0.14	0.50	1.51	4.95
					1000	0.45	1.29	2.12	6.72
					1500	2.00	2.49	5.22	11.15
				1500	500	0.16	0.55	1.60	5.89
					1000	0.64	1.24	2.77	7.19
					1500	3.09	2.17	7.75	12.93
2	50	0	50	500	500	0.04	0.20	1.56	4.55
					1000	0.09	0.44	1.68	4.95
					1500	0.28	0.72	2.36	5.79
				1000	500	0.06	0.19	1.88	4.69
					1000	0.17	0.49	2.23	5.82
					1500	0.45	0.85	3.14	7.21
				1500	500	0.08	0.22	2.17	5.45
					1000	0.31	0.45	3.21	6.49
					1500	0.54	0.79	3.58	7.37
3	80	0	20	500	500	0.02	0.07	1.31	4.06
					1000	0.08	0.16	1.56	4.48
					1500	0.19	0.27	1.92	5.02
				1000	500	0.04	0.08	1.52	4.52
					1000	0.07	0.18	1.57	4.83
					1500	0.24	0.28	2.16	5.35
				1500	500	0.04	0.09	1.67	4.94
					1000	0.11	0.17	1.82	5.01
					1500	0.27	0.25	2.28	5.20

Sl.No.	Tmvt percent			Vol in S,E,W	Vol in North	Avg.Q-len.		Avg.Delay	
	Lt	Rt	Th	Veh/hr	dir.Veh/hr	Q1	Q2	D1	D2
4	0	10	90	500	500	0.05	0.53	1.74	10.53
					1000	0.23	1.20	2.63	12.92
					1500	0.87	2.11	5.22	17.38
				1000	500	0.17	0.65	3.23	14.70
					1000	0.52	1.53	4.30	19.80
					1500	2.94	2.71	14.44	31.65
				1500	500	0.19	0.73	3.32	16.72
					1000	0.87	1.57	6.74	23.86
					1500	5.11	2.53	24.50	43.18
5	0	20	80	500	500	0.08	0.59	2.18	11.33
					1000	0.28	1.30	2.93	14.04
					1500	1.11	2.23	6.25	18.65
				1000	500	0.19	0.75	3.81	16.14
					1000	0.87	1.78	6.95	24.03
					1500	4.52	2.94	21.43	40.60
				1500	500	0.19	0.85	3.49	19.10
					1000	1.19	1.77	9.46	28.27
					1500	11.81	3.00	56.53	77.59

Table 5.4: Results from the sensitivity analysis for 100% through movement and different vehicle mix.

Sl.No.	Veh mix proportion			Vol in North	Vol in S,E,W: 1000 Veh/hr			
	Twowheeler	Heavy veh	Automo.	dir.Veh/hr	Q1	Q2	D1	D2
1	0	0	100	500	0.14	0.50	1.51	4.95
				1000	0.45	1.29	2.12	6.72
				1500	2.00	2.49	5.22	11.15
2	0	50	50	500	0.11	0.65	1.27	5.75
				1000	0.82	1.62	3.42	9.19
				1500	3.20	2.57	8.07	14.19
3	50	0	50	500	0.11	0.46	1.27	4.44
				1000	0.36	1.19	1.80	6.06
				1500	1.52	2.09	4.10	9.06
4	80	0	20	500	0.08	0.44	1.08	4.10
				1000	0.32	1.09	1.65	5.53
				1500	1.23	1.82	3.42	7.74
5	50	10	40	500	0.12	0.48	1.30	4.61
				1000	0.38	1.27	1.88	6.40
				1500	1.75	2.20	4.57	9.83

Chapter 6

CONCLUSIONS

In this thesis a simulation model for unsignalized intersections under Indian conditions is developed. The model can handle different vehicle mix and movements. The model can give as output the delay to each vehicle as well as the queue lengths at various points. The studies conducted with the model show that the model behaves as expected.

However, no validation could be done due to the lack of real world data and this remains the single most important drawback of this thesis. Further a lot of parameters like gap acceptance criteria, travel time from one decision point to the other etc., should have been calibrated using real world data, but could not be done as such data was not available. This is also an important drawback of the proposed model. Another point which must be mentioned here are about delays and queue lengths shown in the results. Although these values increase and decrease as expected, the values themselves may be underestimating the true queue lengths and delays. This underestimation could be due to an erroneous choice of parameters on gap-acceptance, movement of vehicles from one decision point to another, etc. Despite these drawbacks it is felt that the model contributes to the field of transportation engineering by developing a logic which can be used possibly with some modifications to model

the seemingly unruly driving conditions at Indian unsignalized intersections.

It is felt that future work on this model should include calibration and validation using real world data. Once this is done it is felt that the model should be tested under various different conditions and much more extensively than what has been done here.

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